PERFORMANCE EVALUATION BIOMASS COOKING STOVES USED AT HOUSEHOLD LEVEL

M Sc THESIS

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OCTOBER, 2019

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THESIS SUBMITTED TO THE

DEPARTMENT OF ENVIRONMENTAL SCIENCE, WONDO GENET COLLEGE OF FORESTRY AND NATURAL RESOURCE, HAWASSA UNIVERSITY,

WONDO GENET COLLEGE, ETHIOPIA.

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN RENEWABLE ENERGY UTILIZATION AND MANAGEMENT

OCTOBER, 2019

APPROVAL SHEET-1

This is to certify that the thesis entitled **" Performance Evaluation Biomass Cooking Stoves Used at Household Level",** is submitted in partial fulfillment of the requirement for the degree of Master of Sciences with renewable energy utilization and management. It is a record of original research carried out by SENAIT TESFAYE ID. No. MSC/REUM/R014/10, under my supervision; and no part of the thesis has been submitted for any other degree or diploma. The assistance and help received during the courses of this investigation have been duly acknowledged. Therefore, I recommended it to be accepted as fulfilling the thesis requirements hence hereby can submit the thesis to the department.

Kamil Dino Adem (PhD)	____________________	_________________
Name of major advisor	Signature	Date
____________________________	____________________	________________
Name of co-advisor	Signature	Date

APPROVAL SHEET-2

We, the undersigned, members of the Board of Examiners of the final open defense by *SENAIT TESFAYE* have read and evaluated her thesis entitled **" Performance Evaluation Biomass Cooking Stoves Used at Household Level",** and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree of Master of Science in renewable energy utilization and management.

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Name of the Chairperson	Signature	Date
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Name of Major Advisor	Signature	Date
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Name of Internal Examiner	Signature	Date
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Name of External Examiner	Signature	Date
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SGS approval	Signature	Date

ACNOWLEDGEMENT

First and above all, I thank The Almighty God and His Holy Mother Saint Mary for providing me this opportunity and the strength to complete the program successfully.

My greatest words of thanks goes to my principal advisor, Dr Kamil Dino and my co-advisor Professor Tsegaye Bekele for their constrictive advice, support, helpful comments and suggestions during this research work. I am also thankful for the kind supports from Experimental Laboratory at the Ministry of Water, Irrigation and Electricity during experimental process. I appreciate Addis Ababa Environmental Protection Authority for giving the chance to study my M.Sc degree.

My special gratitude is extended to my cousin Zewde for his valuable support during my study. Last but not least, I would like to extend my most profound gratitude to my husband Derese Webshet, my son Bisrat Derese and my families for their love and care during my stay at Hawassa University.

CANDIDET'S DECLARATION

I declare that this thesis is my work and all source of material used in this thesis have been properly acknowledged. This thesis submitted in partial fulfillment of the requirement for M.sc Degree in renewable energy resource management and utilization in Hawassa University .I declare that this thesis is not submitted to any other institution.

Senait Tesfaye Mamo ________________ ________________

Signature Date

ACRONYMS

AETDPL	Alternative energy technology development laboratory
AFREA	Africa Renewable Energy Access
CCT	Controlled Cooking Test
EAC	East African Community
EEPCO	Ethiopian electric power corporation
FDRE	Federal Democratic Republic of Ethiopia
GACC	Global Alliance for Clean Cookstoves
GHG	Green House Gases
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GWP	Global warming potential
IAP	Indoor Air Pollution
ICS	Improved Cooking Stoves
IEA	International Energy Agency
ILO	International Labor Organization
IPCC	Intergovernmental Panel on Climate Change
MME	Ministry of Mines and Energy
MOE	Ministry of education
MoWE	Ministry of Water and Energy
NGO	Non-Governmental Organization
PM	Particulate Matte
UNICEF	United Nations Children’s Fund
VITA	Volunteers in Technical Assistance
WB	World Bank
WBA	World Bio-energy Agency
WBT	Water Boiling Test
WHO	World Health Organization

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ABSTRACT

Cook stoves choice and household energy transition are important from the energy efficiency, health and environmental points of view in Ethiopia . It is imperative to understand alternative cook stoves as substitute for traditional cook stoves with more efficient energy utilization, less environmental and health impacts. Therefore, this study mainly focused on five biomass cook stoves used in Addis Ababa, Ethiopia. The stove were evaluated and compared for their performance by using Water boiling test. Improved cook stoves Lakech, Mirchaye, Flexy, Tikikil, and three stone stove were selected for assessment. The thermal efficiency (TE), specific fuel consumption (SFC), time-to-boil, emission of carbon monoxide (CO), carbon dioxide (CO_2) and particulate matter (PM) were used as performance indicators to compare the cook stove performance. The results of this study indicated that, all improved cook stoves saved fuel wood compared to three-stone stove . The thermal efficiency of three- stone stove was 13% while the improved cook stove showed in the range of 25-32% when usesing solid fuels. However, the thermal efficiency of improved cook stoves which use charcoal as a fuel exhibited a thermal efficiency of 32% for Lakech, 30% for Flexy and 26% for Mirchaye also wood stoves 25% for Tikikil and 27% for Flexy.CO emission from the three-stone fire was higher than that of the improved cook stoves. The average amount of CO emission and particulate matter from the three-stone stove were 1113ppm and 613 µg/m^3 respectively *.While that of the charcoal improved cook stoves were 68.8 ppm and 127* µg/m^3 *respectively .Wood stove showed average CO and PM 371.5ppm and 373* µg/m^3 *respectively . The average amount of CO_2 and NO_2 emission from the three-stone stove were 1.62ppm and 5.8* ppm respectively. *Using clean development mechanism (CDM) methodology, the estimated emission reduction potential of wood cook stoves Flexy and Tikikil were 1.11 and 1.05t CO_2 / device / year, respectively while in the case of charcoal cooking stoves Lakech, Flexy and Mirchaye were 0.065, 0.061 and0.058 t CO_2 / device / year, respectively. Flexy (wood) and Lakech cooking stoves had a better emission reduction potential of GHG from the rest of improve cooking stoves and three stone stoves. The study showed that improved cook stoves namely Lakech and Flexy were better than the three stone stove for the community in terms of thermal efficiency, specific fuel consumption, emission reduction potential and particulate matter emission .Thus, concerned organization should disseminate improved cook stoves for the community so as to protect individuals from negative impact of the three stone stoves.*

***Keywords**: Air pollution, Biomass Cooking Stove, Biomass Fuel, Thermal Efficien*

1. INTRODUCTION

1.1.Background

It is estimated that 40% of the global population relies on combustion of solid biomass fuel to fulfil of their household energy needs (Bonjour *et al.*, 2013). Biomass is not only used for cooking in households and many institutions and service industries, but also for agricultural processing and in the manufacture of bricks, tiles, cement, fertilizers, etc. (Rosillo-Calle, 2010). Most of these people cook on open fires, which burn poorly thus leading to low fuel efficiency and high pollution emissions also causes significant negative impacts of several types, including human morbidity and mortality,outdoor air pollution, climate change and deforestation (Smith *et al*., 2009).Thus, people have aimed at shifting from use of high inefficient cook stove into improved cook stove which are reduced indoor air pollution, reduced forest degradation, and reduced greenhouse gas (GHG) emissions.

The combustion of biomass could be complete or incomplete; when combustion is completed the products are carbon dioxide (CO_2 and water (H_2O). More complete combustion could indicate a lower CO emission factor because in complete combustion, zero grams of CO will be emitted per kilogram of fuel (Lask *et al*., 2015). The combustion of biomass that takes place in the rural areas of developing countries is normally incomplete due to the inefficient cooking stoves being small, simple and locally made (Bhattacharya and Abdulsalam, 2002). Biomass combustion releases CO_2 into the atmosphere, contributing to climate change (Abebe Beyene *et al*., 2015).

Smoke and other emissions from solid-fuel combustion contain thousands of gaseous and particulate chemicals depending on species used (Naeher *et al*., 2007). Exposure to indoor air pollution has been linked to various diseases such as acute lower respiratory infection in children; cardiovascular diseases and cataracts in adults especially women, lung function decrement, interstitial lung disease and respiratory symptoms such as nasal discharge, cough, shortness of breath, and chest tightness (Smith *et al*., 2007; Khalequzzaman *et al*., 2007).. Improved cooking stoves were developed primarily for their potential to improve household health, local environmental quality, and can reduce the amount of fuel required, time and effort spent gathering fuel, and cooking times – all of which have the potential to improve health and increase household welfare (Lewis and Pattanayak, 2012) ,Although improved stoves can make cooking with fire easier, safer, faster, and can add to the beauty of the kitchen (Sumit *et al*., 2017). Currently more than 160 cooking stoves programs are running in the world (Gifford and Mary Louise, 2010).

Ethiopia is endowed with substantial energy resources, such as hydropower, Biomass, geothermal, solar, wind and coal energy. As different studies indicate almost 96% of the country's energy demand is met by biomass energy, which is mostly covered by wood, charcoal, crop residue and dung.Therefore, the total supply of this fuel, 93% is used for meeting household energy needs for cooking (Workeneh Gashie, 2005).

In Ethiopia, the benefits of improved cooking stoves are very significant. Under the Clean Development Mechanism (CDM),there is an increasing number of projects and programs distributing ICS (Dresen *et al*., 2014). Consequently, governmental and NGOs have been involved in the development and dissemination of different types of improved biomass cooking stove technologies since 1970s (EPA, 2004).As aresult alternative technology is considered as the potential to minimize energy losses and the negative environmental impacts of the traditional biomass energy utilizations. However, in the study area, some users are not oriented about the efficiency, the fuel consumption, the impact of the environment and the potential emission reduction of each cook stoves available in the market. The main driver for promoting these stoves has been to reduce environmental degradation resulting from the removal of trees for charcoal and fuel wood production (Biruk Fikadu, 2011.).“Reducing the demand for biomass by increasing fuel efficiency” is indeed currently seen as one of the few strategic priorities in the Ethiopian energy sector” (FDRE, 2014).

1.2. Statement of the Problem

The heavy dependence fuelwood and inefficient utilization of biomass cooking stove have resulted in high depletion of the forest resources in Ethiopia (EPA, 2004). Lack of clean and affordable biomass cooking stove has been recognized as a significant barrier to development and major contributor to a host of environmental and human health problems (David *et al.*, 2013). Many of the past biomass cooking stoves programs has failed due to the lack of proper understanding of the needs of the people who use this technology (World Bank, 2011). The demand for local biomass energy used to cooking and heating may exceed the natural re-growth of local resources and causes deforestation from which environmental problems can result. The biomass fuels burned in traditional cooking stove release inefficient energy and large amount of pollutant gases (Naeher *et al*., 2007).

The existence of high demand for traditional biomass fuel leads to health and environmental degradation problems, which have effects on agricultural productivity and poverty. Three stone stove release unsafe amounts of harmful emissions that are proven to have significant adverseeffects on the health of women and children present in the cooking space (WHO, 2014, Bruce *et al.* 2002;Ezzati *et a*l.,2000). The contribution of fuelwood conservation to reduced forest degradation and therefore fewer carbon emissions depends on the nature of fuelwood harvest (Johnson *et al*., 2010;Lee *et al*., 2013).

Therefore, issues related to cooking stoves choice and household energy transition are important from energy efficiency, health and environmental points of view in Ethiopia. This study has investigated alternative cooking stoves as substitute for three stone stoves with more efficient energy use, less environmental and health impacts.

1.3. Objectives

1.3.1. General objective

The overall objectives of this study was to evaluate biomass improved cooking stoves used in Addis Ababa and compare them with three-stone cooking stove at laboratory level.

1.3.2. Specific objective

The specific objectives of the study were:

- To conduct the performance evaluation of improved cooking stove: Flexy, Lakech, Mirchaye and Tikikil
- To analyze emission of carbon monoxide (CO) Carbondioxide (CO_2) , Nitrou oxide (NO_2) and Particulate Matter (PM) using three stone cooking stove and improved cooking stoves.
- To estimate the GHG reduction potential of biomass cooking stove in Ethiopia.

1.4. Research question

- What is the performance of improved biomass cooking stoves operating in Addis Ababa Ethiopia at laboratory level?

- What are the indoor air pollution associated with the use of improved and three stone cooking stoves?
- What is the GHG reduction potential of improved cooking stoves in Ethiopia?

1.5. Significant of the study

performance of the improved cooking stoves is going to be tested and compared with the three stone stoves based on standard performance parameters; thermal efficiency, specific fuel consumption, duration of cooking and concentration of pollutants during the cooking using standard methodology. As a result, the finding of this study would contribute to a more effective source of information to the various efforts directed to reduce cooking inefficient energy source used and the impact on environmental pollution. In addition, it will be used as a reference material for similar and related studies concerning biomass cooking stoves used and the adaptation of improved cooking stoves.

This study may be also used by standardizing institutions as source of data to standardize different cooking stoves in terms of the parameters put here on, so that consumers can select easily the better ones.

1.6. Limitation of the Study

The study was conducted using only water boiling test in a laboratory. However, it would have been a detail evaluation of cooking stoves if it was possible applied control cooking test and kitchen performance tests. The application of control cooking test and kitchen performance tests require high budget and takes a longer period of time as they require field assessment of household and cooking of real meal.

2. LITRATURE REVIEW

2.1. Energy resources in Ethiopia

Energy is an essential thing for life. Human beings have always depended on energy to prepare their food, to heat buildings, for lighting and to manufacture different materials and machineries in factories, and industries. According to (Workeneh Gashie, 2005), Ethiopia has significant energy resources, such as hydropower, biomass, solar, wind, coal and geothermal and almost 96% of the country's energy demand is met by biomass energy, which is mostly covered by wood, charcoal, crop residue and dung. Ethiopia is endowed with all sources of energy such as hydro, solar, wind, biomass, natural gas, geothermal, etc., it has not been able to develop, transform and utilize these resources for optimal economic development (Mulugeta Biadgo Asress *et al*., 2013). Exploitable natural gas, coal and renewable energy potential of Ethiopia are given in Table1.

Table: 1. Exploitable Potential of Energy Resources in Ethiopia [Mowe, 2011, Eepco 2011]

Resource	Unit	Exploitable potential
Biomass	Million metric ton/year	75
Hydropower	MW	45,000
Solar	kWh per meter square per day	5–6
Wind	MW	10,000
Geothermal	MW	5000
Natural Gas	Billion cubic meter	113
Coal	Million ton	400

2.2.The general use of energy in Ethiopia

Energy is a critical requirement for human life. It deeply influences all aspects of human welfare: food preparation and preservation, access to water, agricultural productivity, health care, education, job creation, climate change, and environmental sustainability (Bonjour *et al*.,

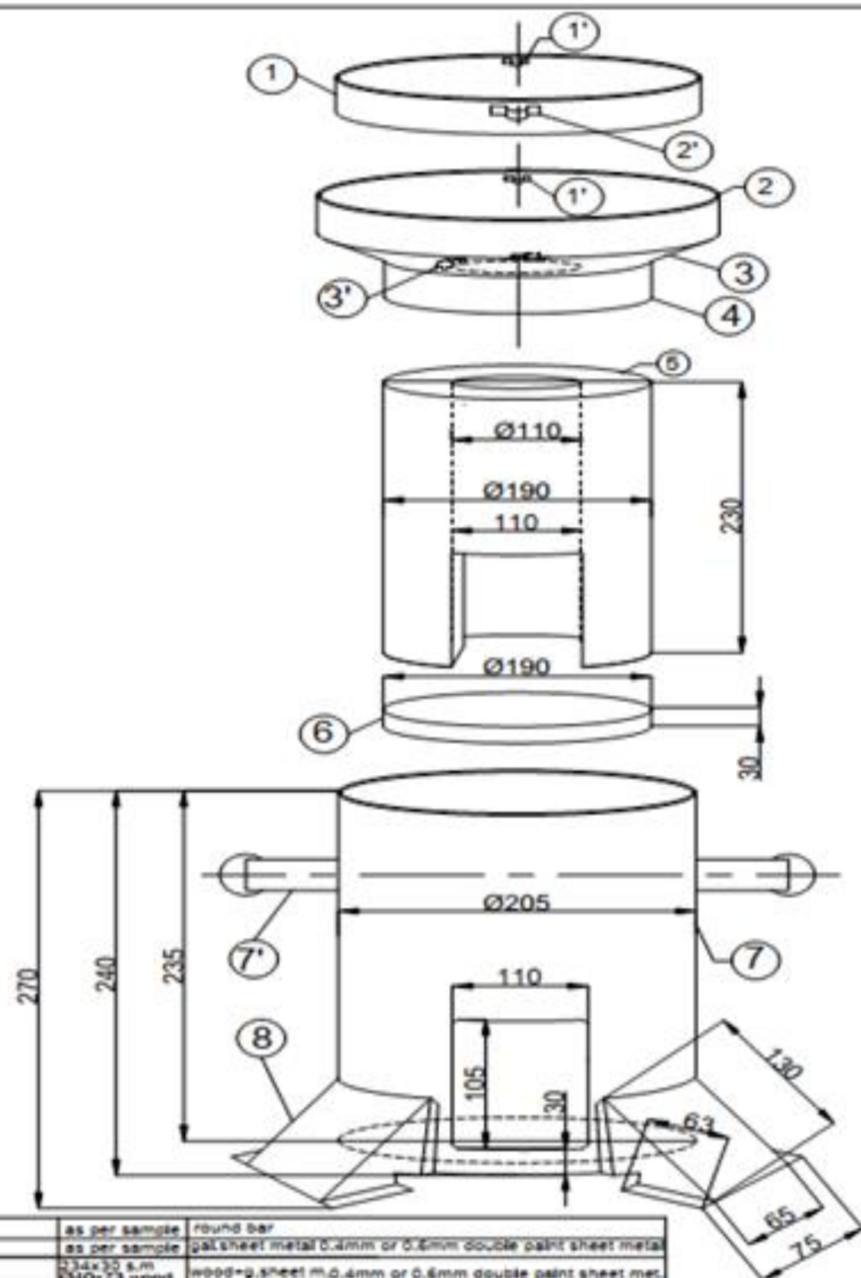
2013) . Solid biomass fuels (fuel wood, charcoal, animal dung, and crop residues) are the main sources of cooking for more than 90% households in Ethiopia (Tower and Box, 2018). According to (Workeneh Gashie, 2005), Ethiopia has important energy resources, such as hydropower, biomass, solar, wind, coal and geothermal. National energy balance of Ethiopia has been so far predominate by two sort energy resources ,they are Hydro and Biomass (Dawit Diriba Guta, 2012).Similarly Ethiopia is a typical example, where nearly all its rural population depends on biomass energy sources for cooking and other energy requirements (Alemayehu Zeleke Urge and Motuma Tolera Feyisa, 2019). The national energy balance indicates that traditional fuels (wood, charcoal, agricultural residue and animal waste) meet 94% of the total energy supplied and that the household sector accounts for 90% of total energy consumed in the country (Biruk Fikadu, 2011). According to climate resilient green economy CRGE ,(2011.) strategy of Ethiopia (2011), fuel wood (fire wood and charcoal) consumption in Ethiopia has led to woody biomass degradation of about 14 million tons in 2010 and this is projected to increase to about 23 million tons in 2030 due to expected continual use of biomass for cooking and baking.

2.3. Biomass cooking stove in Ethiopia

Ethiopia's energy consumption is predominantly based on biomass energy sources, with 95 % of its primary energy consumption coming from renewable energy sources. Biomass cooking stove is heated by burning wood, charcoal, animal dung or crop residue. Cooking stoves are used for cooking and heating food in rural and urban households in Ethiopia. Wood is still the largest source of biomass based fuel used in the world today (GACC, 2012d), and also the most common energy resource in Ethiopia (AFREA, 2011).

Charcoal cooking stoves are the most widely used in urban and rural area of Ethiopia. Charcoal cooking stove used for cooking ‘Wat’, boiling water, making coffee, heating home and other related activities. The use of these stoves increases with the rapid growth of urban population of the country. Charcoal cooking stoves are light weight, portable, have one fire per pot, and have no chimney. Traditional and improve cooking stove are used for charcoal and wood. Fig 1 that shows biomass cooking stoves.

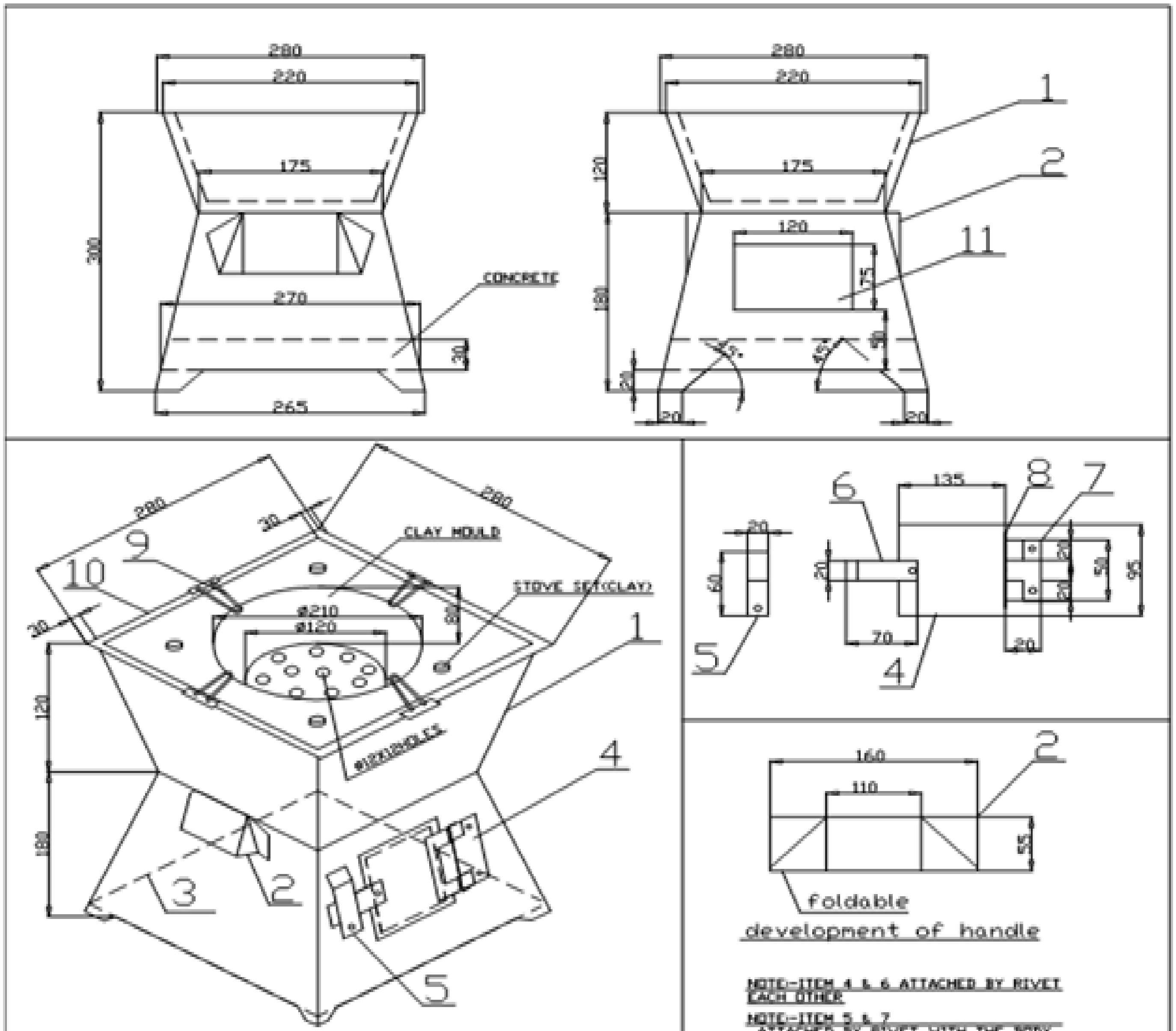
Fig: 2.1.Biomass cooking stoves



ITEM	Pcs.	COMPONENT PARTS	DIMENSION	MATERIAL
9	1	GREET	as per sample	round bar
8	3	FOOTING	as per sample	gal.sheet metal 0.4mm or 0.6mm double paint sheet metal
7'	2	HANDLE	234x30 s.m Ø40x73 wood	wood+g.sheet m.0.4mm or 0.6mm double paint sheet met.
7	1	MAIN BODY	Ø205x240	gal.sheet metal 0.4mm or 0.6mm double paint sheet metal
6	1	ASH DUMP	Ø190x30	clay
5	1	CLAY MOULD	Ø190x230	clay
4	1	COVER SEAT	Ø171x90	gal.sheet metal 0.4mm or 0.6mm double paint sheet metal
3'	1	POT REST	as per sample	1mm double paint sheet metal
3	1	POT REST COVER	Ø345x20	gal.sheet metal 0.4mm or 0.6mm double paint sheet metal
2'	3	POT REST GUP	75x27	gal.sheet metal 0.4mm or 0.6mm double paint sheet metal
2	1	POT REST COVER	Ø293x85	gal.sheet metal 0.4mm or 0.6mm double paint sheet metal
1'	3	POT REST GUP	38x27	gal.sheet metal 0.4mm or 0.6mm double paint sheet metal
1	1	POT REST SCERT	Ø293x85	gal.sheet metal 0.4mm or 0.6mm double paint sheet metal

		Sheets No.
DATE	NAME OF THE ENSEMBLE tekkel stove with scert	
DES.		
DR.	NAME OF THE DWG. tekkel stove with scert	
APP.		
SCA.		
ALL MEAS. IN MM	DR.No.	

Fig:2.2 Schematic Drawing of Tikikil Stove



ITEM	Pcs.	COMPONENT PARTS	DIMENSION	MATERIAL
11	1	AIR INLET	75X120X0.8	SHEET METAL
10	1	CLAY COVER	280X280X0.8	SHEET METAL
9	4	POT REST	ø6X275	ROUND IRON
8	1	HINGE PIN	ø3X70	ROUND IRON
7	2	HINGE	20X50X0.8	SHEET METAL
6	1	LOCKER	20X70X0.8	SHEET METAL
5	1	LOCKER	20X60X0.8	SHEET METAL
4	1	INLET DOOR	75X120X0.8	SHEET METAL
3	1	FOOTING	0.8X265X265	SHEET METAL
2	2	HANDLE	55X160X0.8	SHEET METAL
1	4	BODY	300X280x0.8	SHEET METAL

EREDPC	DATE	NAME OF THE ENSEMBLE MERCHAYE CLAY MOULD MIDIUM
DES.		
DR.		NAME OF THE DWG. MERCHAYE CLAY MOULD MIDIUM
APP.		
SCA.		
ALL MEASURMENT IN MM		DR.No.WL

Fig: 2.3.Schematic Drawing of Mirchaye Stove

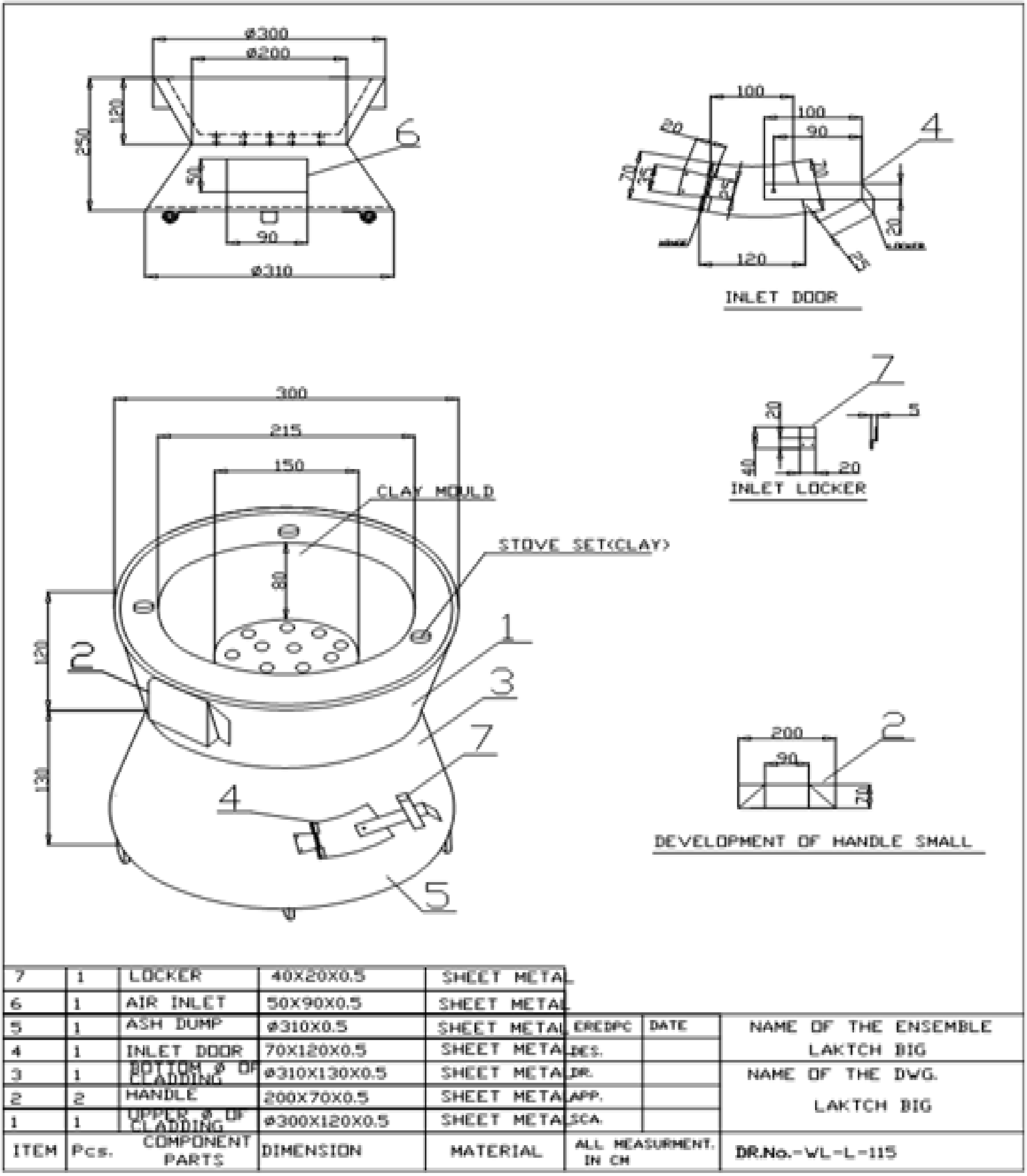


Fig: 2.4. Schematic Drawing of Lakech Stove

2.4. Traditional cooking stove in Ethiopia

The open-fire or traditional cooking stove transformed into shielded-fires to balance the pot over the fire. The initial and simplest form of the shielded-fire was a three-stone arrangement. In this arrangement, the stones were arranged at suitable angles on the plain ground to support the pots of various, which improved the cooking efficiency and reduced the scattering of fire from windy conditions (Kumar, 2013). Cooking stoves can range from three-stone open fires that show in Fig .1.1 (b). Three stone stove requires large amount of fuel and is fairly inefficient at converting energy into heat, adds to an increase in deforestation and time spent for collecting fire wood. although the three-stone stove consumes large amount of solid biomass due to its low burning efficiency which may additionally lead to deforestation and soil erosion (Sutar *et al*., 2016). They are cause indoor air pollution and health problems, and contribute to global warming. Three stone stove biomass cooking stoves have low thermal efficiency and high smoke emissions compared to improved cooking stoves (Panwar and Rathore, 2008). According to Rasoulkhani *et al*., (2018) the thermal efficiency of the ICS in the cold start phase was approximately 35 %, while for the TCS it was only 12.6 % .

2.5. Improved cooking stove in Ethiopia

Hundreds of types of improved cook stoves have been developed across the world ever since the shortcomings of the traditional designs became known (Sutar *et al*., 2015). Improved cooking stoves (ICS) are designed with the aim to get better cooking efficiency and release fewer pollutants (Mehetre *et a*l., 2017). Improved biomass cooking stove have the potential to reduce the negative impacts of current traditional biomass energy use. According to Collins,(2015) An improved cooking stove differs from a traditional cooking stove via two main facets; first, an improved cooking stove delivers heat to the food more efficiently than a three stone stove and second, an improved cooking stove will have lower emissions per unit of energy delivered to the food than a three stone stove. Many policy makers and researchers in the developing world as well as interested decision makers in the more developed parts of the world are keen to see a progressive shift from traditional biomass use to improved use, and eventually to modern biomass energy use (Karekezi and Kithyoma,2002).According to (Zenebe Gebreegziabher *et al*., 2018) Improved biomass cooking stove is one that provides fuel savings and convenient use, including reduced or similar cooking times and educed fuel requirements in turn can translate into either reduced expenditures or household time savings that can be used for other purposes, including free time. It also can translate into reduced indoor air pollution, reduced forest degradation, and reduced greenhouse gas (GHG) emissions. Relatively simple ICS technologies that can meet actual user needs through less biomass use and convenience, and that require only minor changes in household cooking habits, are therefore potentially important intermediate technologies (Jeuland and Pattanayak, 2012) .P. R. Bailis et al., (2007) suggested that the improved cooking stoves may be able to reduce the solid biomass fuel consumption by 19-66 %. The major stoves developed for pot-sized stoves (nonbanking cookstoves) were *Tikikil* and *Lakech* stove (Tower and Box, 2018). Zhang *et a*l., (2017) have indicated that improved cooking stoves (ICS) reduce the emission of health-risky pollutants in the short term and reduce greenhouse gases (GHG) emission in the long term. Recently Fikadu Mamuye *et al*., (2018) suggested that the use of improved charcoal stoves (Mirchaye and Lakech) in Ethiopia could help to mitigate climate change, deforestation, and household workload. According to Uckert, (2016) after the millennium the promotion of ICS programs regained attention on donor organization and non-governmental organization (NGO) level. Worldwide more than 160 improved cooking stoves programs were reported to be running in 2011, focusing on wide dissemination of improved cooking stoves (Ruiz-Mercado *et al*., 2011). According to(Tsige Simur Asres, 2012) some parts of Ethiopia International Labor Organization (ILO), Efficiency Program Planning in Ethiopia (CEPPE),Ministry of Agriculture (MoA), the Rural Technology Promotion Centers (RTPCs) under the MoA, the Ministry of Education (MoE) funded by UNICEF, the German Development Cervices (DED) has disseminate and promoted improved wood and charcoal cooking stove.

2.5.1. Lakech improved cooking stove in Ethiopia

Lakech stove was adopted from the Kenyan Ceramic Jocko, locally known as KCJ, by the Ethiopian Energy Studies and Research Center of the Former Ministry of Mines and Energy in 1990 under the Cooking Efficiency Improvement and New Fuels Marketing Project to (Workeneh Gashie,2005). This stove is made from ceramic liner with a cladding and developed by cooking efficiency improvement and new fuels marketing program based on the Kenyan ceramic joke show Fig .2.1(d) and Fig .2.4 . It utilizes charcoal for non *Injera* cooking (Biruk Fikadu, 2011). Recently in Ethiopia the governmental and nongovernmental organization are trying to minimize energy loss by introducing improved biomass cooking stoves. The first improved cooking stove designed and distributed was '*Lakech*' (better) charcoal stove (Mulugeta Biadgo Asress *et al*., 2013). The informal sector is highly involved in the production and disseminating of the stoves and the stove is predominantly produced in large towns like Addis Ababa and transported to different regions (Tower and Box, 2018).These stoves have saved one fourth of the energy than the traditional metal charcoal stoves (GTZ, 2007).According to GTZ, a single *Lakech* stove saves 0.125 kg of charcoal per household per day.

2.5.2. Mirchaye improved cooking stove in Ethiopia

Mirchayle is another name of Obama; Mirchayle stove is very similar to the Lakech stove in that it is in an improved charcoal cooking stove but differs in that Mirchayle can use charcoal and briquettes as well as normal charcoal pieces as a fuel source show Fig.2.1(e) and Fig.2.3 . The stove is comparatively new to the market and becoming preferable by refugee camps and households is buying the stoves direct from stove producers also the marketing and dissemination nature of the stove is taking after the Lakech stove practice (Tower and Box, 2018).

2.5.3. Tikikil improved cooking stove in Ethiopia

GTZ SUN Energy (Sustainable Utilization of Natural Resources) has been lately working with local potters and metal artisans for local manufacturing of a household rocket cooking stove which would be affordable for low income households show Fig .2.1(a) and Fig.2.3. "Tikikil" tailer made and optimized to accommodate a 25 cm diameter of pot size which is typical size used in households. The stove has an inner clay liner for the combustion chamber covered with sheet metal on the outside. The clay liner is produced by local potters while the metal covering is done by metal artisans. The stove has non removable skirt. The wood shelf is made up of 5mm radius round metal bar (GTZ, 2009). Tikikil cooking stove same similarity from Ugastoves which are manufactured in a factory of Uganda and have different sizes and shapes (Adkins *et al.*, 2010). The rocket-type wood-burning stove has a metal "pot skirt" permanently fixed to the outer edge of the top of the stove. The Ugastoves are manufactured in several sizes (Urmee and Gyamfi, 2014a). Fuel efficiency of up to 36 % has been reported for charcoal stoves and 58% for the wood rocket types (Adkins *et al.*, 2010) .

2.5.4. Flexy improved cooking stove in Ethiopia

Flexy is the rocket type improved cooking stove show in Fig .1 (c). There are two major types; improved charcoal stove and wood stove for household use. Rocket-type stoves are able to reduce CO emissions due to higher temperatures and better mixing with flame (MacCarty *et al.*, 2010a). Although Hall,(2014) studied that the rocket-stove design originally used for the stove ensures that combustion occurs in the space directly above the fire; this ensures lower carbon emission. They have a ceramic liner enclosed in a sheet of metal Although Envirofit boast the world's most fuel efficient cookstoves, producing 80 % less smoke and harmful gas emissions, 60 % less biomass fuel (wood, crop waste, etc) consumption and up to 40 % reduction in cooking cycle time, compared to the traditional three stone open fire (Urmee and Gyamfi, 2014b).

2.6. Role of improved cooking stove on the environment

Improved cooking stoves were developed primarily for their potential to improve household health, local environmental quality, and for regional climate benefits. Compared to three stone stoves, ICSs improve cooking efficiency and can reduce the amount of fuel required, time and effort spent gathering fuel, and cooking times – all of which have the potential to improve health and increase household welfare (Lewis and Pattanayak, 2012). Thus, the two essential benefits of most improved stoves programs are their environmental, health, as well as socioeconomic impacts.

The improved stove is composed of two main parts: a circular pot-opening part on the top of a cylindrical combustion chamber featuring a clay layer in between two metal sheets insulation allowing the stove to conserve heat and burn more efficiently. Furthermore, estimated economic and environmental impacts of adopting improved stoves can be quite significant for communities. A large number of empirical studies identify different benefits as well as costs associated with a household's decision to use improved cook stoves and fuels. From the users' perspective, benefits include reduced air pollution, time saved from collecting fuels, and fuel cost savings, as well as aesthetic gains and improved social standing (Malla and Timilsina, 2014).

2.7. Impact of traditional cooking stove on the environment and health effect

2.7.1. Environmental impact of traditional cooking stove

Traditional cooking stoves in the rural areas are low efficient due to the incomplete combustion of the fuel wood (Hossain, 2003). To make things bad, products of incomplete biomass combustion also act as greenhouse gases and thus contribute to the global warming (Jeuland and Pattanayak, 2012) .

Three stone stove and inefficient cooking stoves using solid fuels because a range of harmful impacts that impede economic and social development and lead to significant loss of life in the developing world. Clean cooking stoves and fuels have the potential to reduce deaths from smoke-related illnesses, mitigate climate change, and lower air pollution. They can provide new sources of livelihoods for women while reducing the risk and labor of fuel collection, and can lower household expenditures on cooking fuel.

The combustion process in three stone fire cooking stove is non-ideal and favoring incomplete combustion (Panwar *et al*., 2011). Incomplete and inefficient combustion by three stone cooking stoves produce significant quantities of products of incomplete combustion (PIC) comprising of fine and ultra fine particles which have more global warming potential (GWP) than CO. Emission study was also conducted by Bhattacharya and Abdulsalam,(2002) was concluded that incomplete combustion of biomass in the three stone cooking stove released carbon monoxide (CO), nitrous oxide (N_2O),methane (CH_4), polycyclic aromatic hydrocarbons (PAHs), particles composed of elemental carbon or black carbon, and other organic compounds. High biomass energy consumption along with inefficient utilization has contributed for deforestation, biodiversity loss and land degradation (Abebe Damte *et al*., 2011).

2.7.2. Health effect of traditional cooking stove

Biomass is burnt inefficiently in open three-stone fires cooking stoves for cooking, and heating applications . Hence, it causes severe health problems in women and children and also affects the environment (Kumar, 2013). Cooking activities, regardless of the use of biomass as an energy source, release a number of air pollutants. Some of them can cause odor nuisance, whilst being hazardous to human health (Kabir and Kim, 2011). Indoor air pollution represents a major environmental and health problem. Wood smoke is known to contain many dangerous pollutants, and the two most commonly used in indoor air pollution assessments are particulate matter with an aerodynamic diameter less than 2.5 µm(PM) and carbon monoxide (CO), both of which serve as indicators of overall wood smoke exposure and are themselves harmful to health (Naeher *et al*., 2007).

2.8. The performance evaluation method of cooking stove

The methods used for this study were those that are developed by Volunteers in Technical Assistance (VITA), NGOs focusing on third world development issues. The first serious efforts to develop test protocols specifically for biomass cookstoves was facilitated by Volunteers in Technical Assistance (VITA) in 1982 (L'Orange *et al*., 2012). The VITA method has three standard tests: Water Boiling Test (WBT), Kitchen Performance Tests (KPT) and Controlled Cooking Test (CCT). Possible approaches to measure how much fuel wood is used per unit of time include randomized kitchen performance (KPT), controlled cooking (CCT) and water boiling (WBT) tests. Each has its advantages and drawbacks (Lee *et al*., 2013)

2.8.1. Water boiling test

The 2003 Revised University of California-Berkeley (UCB) Water Boiling Test (WBT) Version 3.0 was used to evaluate all of the stoves (R. Bailis *et al*., 2007) This was based on the original WBT developed in the 1980s (VITA,1985), the protocol has faced many updates and reviews, with contributions by different authors and research teams leading to its last revised version of 4.2.3 in 2014 (Colombo *et al*.,2016). More recently, the group of Engineers in Technical and Humanitarian Opportunities of Service (ETHOS) has developed a Water Boiling Test code, WBT 4.2.3 (GACC, 2014) in collaboration with Clean Indoor Air (PCIA) and Global Alliance for Clean Cookstoves (GACC). The Water Boiling Test is a relatively short and simple simulation of common cooking procedure in which a standard quantity of water is used. The test includes “high power” and “low power” phases. The high power phase involves heating a standard quantity of water from the ambient temperature to boiling temperature as rapidly as possible the maximum boiling point. In the low power phase, the power is reduced to the lowest level needed to keep the water simmering. In this study a pot of water is brought to boil and is kept boiling followed by a simmering period of 45 minutes. Water boiling test is intended to measure the stoves’ performance at both high and low power output, which are important indicators of the stoves’ ability to conserve fuel.

The WBT is a laboratory simulation of a basic cooking process that can be performed on most stoves while operating at both high and low power. “While the test is not intended to replace other forms of stove assessment, it is designed to be a simple method by which stoves made in different places and for different cooking applications may be compared by a standardized and replicable protocol" (R. Bailis *et al*., 2007), While there are many other methods for testing cooking stoves used by governments and organizations around the world, the Water Boiling Test was chosen because it has been written and continually revised by the cooperation of international experts in the field. Alsot he test is designed to yield several numerical indicators including; time to boil, burning rate, specific fuel consumption and power output rather than reporting a single number indicating the thermal efficiency of the stove, which alone cannot accurately predict stove performance.

2.8.2. Controlling cooking test

The CCT was developed to be an intermediary test, a test where stoves are used to cook real meals but under more repeatable conditions (Bussman *et al*., 1985). Technical aspects of stove performance were evaluated using a modified version of the Controlled Cooking Test (CCT) protocol developed by the University of California-Berkeley and Shell Foundation Household Energy and Health Projects (Bailis, 2004).

2.8.3. Kitchen performance test

The kitchen performance test (KPT) is a type of field test, carried out in actual kitchens. Through KPT, researchers assess the actual effect of ICS on household fuel use; and study qualitative stove performance aspects, through household surveys also KPTs generally during the actual stove dissemination process, with actual users cooking on the stoves as usual (Kshirsagar and Kalamkar, 2014). It evaluate stove performance in real-world settings and designed to assess actual impacts on household fuel consumption. KPTs are typically conducted in the course of an actual dissemination effort with real populations cooking normally, and give the best indication of real world changes.

3. MATERIAL AND METHODS

3.1. Description of study condition

3.1.1. Description of the biomass cook stove

The five cooking stoves evaluated in this study as shown in Fig 2.1.Tikikil wood burning cooking (a), three stone stove or traditional cooking stove (b) , Flexy wood and charcoal stove (c) , Lakech cooking stove (d) and Mirchaye cooking stove(e) were the five cooking stoves selected because they are among the most commonly used biomass cooking stoves in Addis Ababa. This is due to the fact that low and middle income groups frequently use biomass cooking stoves as cooking instruments. These cooking stoves were purchased at local markets of Shola around Megnagna in Addis Ababa.

The laboratory where the different stoves evaluated is located in the Addis Ababa, at Yeka sub city around Gurd Shoal Woreda 9. The laboratory belongs to the Ministry of Water, Irrigation and Energy . Fig 3.1 show the room of the laboratory where different test were conducted .

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Fig :3. 1. Inside the laboratory of MWIE

3.1.2. Fuel types

Two locally available solid biomass fuels- fuel wood and charcoal were used during the study. These fuel woods and charcoal were available in the market. The common fire wood in Ethiopia is Eucalyptus Globules . The wood sample were dried properly using sun light and measured using moisture analyzer.The moisture content of the sample wood found out to be 8 %. The average size of the wood pieces was (l ×w ×h) 48 cm × 3.3 cm × 10 cm. The amount of wood used was 2000g for Tikikil , Flexy and three stone stove respectively . The calorific value of the fuel wood was measured using a bomb calorimeter was 20,160 kJ/kg as standard.

The charcoal was broken into small pieces of different size. Charcoal samples, analyzed using standard oven-drying procedures and found to have a moisture content of 3 %. The amount of charcoal used in each stove was adjusted for the fuel bed size of that stove. A size of 230 g charcoal is used for the Mirchaye , Lakech and flexy .Fig .3.2 shows fuel that was used in the experiment and measured using balance

Fig:3. 1. The type of fuel used in the experiment wood and char coal

3.1.3. Pots types

In this study, the volume of aluminum pot was three liters where 2.5 liters of water would be poured for water boiling test. The same pot and same amount of water is used throughout all test phases and replicates.

3.3. Procedure used during test

Each of these tests were performed three times after allowing the stove to cool down before starting the next round and the average of three trial test is taken to obtain the thermal efficiency of the stove. Data were analyzed in conjunction with the WBT 4.2.3 data calculation spreadsheet. The WBT requires three test phases, namely the cold start, hot start, and simmer phases. The cold start phase is the first phase of the WBT where in the cooking stove and 2.5 L of water is initially at room temperature. The cold start phase is immediately followed by the hot start phase, where 2.5 L of water at room temperature is heated, using the same stove which is still hot. The simmer phase comes after the hot start phase, where the remaining water from the previous phase is constantly heated within 3℃ below the boiling point for 45 minutes. The cold and hot start phases end when the water has come to a consistent boil. Parameters measured at the start and at the end of each phase were the initial temperature of the water, the weight of the pot with and without water, the weight of both the charcoal and the resulting ash, and the time. Test is focusing on thermal efficiency, burning rate, fuel consumption, fire power, turn-down ratio (ratio of the stove's high power output to its low power output), fuel and time use. Most test procedures boil a certain amount of water and measure biomass inputs and the required time to fulfill the task (MacCarty *et al*., 2008).

3.4. Parameters

3.4.1. Thermal Efficiency

Thermal efficiency is calculated as the ratio of the heat absorbed by water and the heat produced by combustion; the former is computed as the sum of sensible and latent heat, while the latter is computed as fuel consumed times lower heating value of the fuel, both on a dry basis which adjusts the amount of dry fuel that was burned using equation 1 (GACC,2014).

$$\eta = \frac{4.186(T1_{cf-}T1_{ci})\,(P1_{ci-}P1_{cf})+2260\,.W_{cv}}{f_{cd.}LHV}$$ ------------------------------1

Where

$C_P A$ = specific heat capacity 4.186$[\frac{KJ}{KgK}]$

$T1_{cf}$ = Water temperature at end of test (ºC)

$T1_{ci}$ = Water temperature at start of test (ºC)

$P1_{ci}$ = Mass of pot of water before test (grams)

$P1_{cf}$ = Mass of pot of water after test (grams)

w_{cv} = Water vaporized (grams)

Δh_{HH_2Ofg} = specific enthalpy of vaporization can be approximated as = 2260 $\left[\frac{KJ}{Kg}\right]$

LVH= Net calorific value in KJ/Kg (dry wood or charcoal)

f_{cd} = Equivalent dry wood consumed (grams)

The "equivalent dry fuel consumed", adjusts the amount of dry fuel that was burned in order to measure the energy that was needed to remove the moisture in the fuel and the amount of char remaining unburned ,tha tcould be calculate using Equation 2 (GACC,2014).

$f_{d=}dry\ fuel\ - fuel\ to\ eva.water\ -\ fuel\ in\ char$--2

3.4.2. Specific fuel consumption

Specific fuel consumption is mainly used to find out the fuel spent to complete the WBT per unit mass of water boild. The specific fuel consumption rate is corrected for the initial temperature of the water, the moisture content of the fuel, the energy expended to evaporate the moisture of the fuel and quantity of water evaporated (MacCarty *et a*l., 2010) . Analysis of specific fuel consumption is the first step in quantifying the difference between cooking stoves, since the amount of fuel burned is directly related to the amount of temperature and pressure. Amount of fuel required to complete the WBT cooking task: to bring 2.5l of water to boil and then simmer the remaining water for 45 minutes. This data was taken the average of three trial test . For comparison on the same scale, mass of each fuel used (wood or charcoal) is converted to energy consumption based on the calorific value for the fuel. SFC is calculated as the ratio between the equivalent dry fuel consumed and the final mass of water in the pot (GACC, 2014)

$$SFC = \frac{f_d}{m_{w.f}} \left[\frac{kg_{fuel}}{kg_{water}}\right] \text{--} 3$$

Note; 1kg $_{water}$ = 1l, the WBT expresses SFC as kg $_{fuel}$ /l

Where, f_d =Equivalent dry fuel consumed

$m_{w.f}$ =Final mass of water at the end of a phase

3.4.3. Time to boil

The time-to-boil is the amount of time it takes for 2.5 L of water to reach the local boiling point. The local boiling temperature is influenced by several factors including altitude, minor inaccuracies in the thermometer, and weather conditions. For these reasons, the local boiling temperature cannot be assumed to be 100 ℃. For a given altitude h (in meters), the boiling point of water may be estimated by the following formula: (GACC, 2014)

$$T_b = (100 - \frac{h}{300})\ ℃ \text{---} 4$$

The Time-to-boil in this WBT was recorded from when the charcoal was considered lit until the water started boiling. Time needed to boil 2.5 L of water was calculated as the difference between start and finish times using Equation (GACC, 2014)

$$\Delta t = t_f - t_i \text{--} 5$$

Where Δt- total time (min) to boil

t_f – Time at the end of test

t_i- Time at the start of the test

3.4.4. Measurement of PM 2.5 and CO in the hood

Hood system was widely used for testing the small cooking stove without a chimney (Figure 4). A well-controlled fan was used at the end of the hood system. The measurement of PM2.5 is conducted with portable air detector that put inside the hood. (Optional for emission measurements). Record the concentrations of CO_2 (ppm), CO (ppm) , NO_2 (ppm) and particulate matter concentrations (µg/m^3) (WBT- V4.2.3, 2014) .The PM 2.5 is collected using the detector that measure PM 2.5 and then the values are recorded manually. Five hundered g of wood and 230 g of charcoal are used for cooking stove and the time intervalused for recording the data was 5 min . The maximum detectable value of PM 2.5 the instrument read is 999mgm^{-3}. The measurement system includes two parts: a flue gas analyzer (testo330-2LL) that directly sampled gas and measured real-time concentrations of CO ,CO_2 and NO_2.

Fig: 3.3. Hood Test System

3.4.5. Estimation of the carbon dioxide (CO_2) reduction

Estimate of the carbon dioxide (CO_2) reduction is calculated using the AMS-II G methodology (UNFCC, 2012). Emissions reduction from the use of efficient cooking stoves are calculated as a product of the amount of woody biomass saved, i.e. fuel consumption, the fraction that is considered non-renewable biomass (fNRB), the emission factor for fossil fuel and the net calorific value (NCV) of biomass (Lee *et al*., 2013).The CDM methodology AMS II.G uses the following equation for calculating emission reductions. Where charcoal is used as the fuel the quantity may be determined by using a default wood to charcoal conversion factor of 6 kg of firewood (wet basis) per kg of charcoal (dry basis) (UNFCC , 2012).

$$\mathrm{ER}_{\mathrm{y},} = \mathrm{B}_{\mathrm{y},} \times \mathrm{f}_{\mathrm{NRB,y}} \times NCV_{Biomass} \times \mathrm{EF}_{\text{project fosilfuel}} \times \mathrm{N}_{\mathrm{y,(ICS)}} -------6$$

Where:

ER_{y} = Emission reduction during year y in $\mathrm{tCO2eB}_{\text{y,saving(ICS)}}$

$\mathrm{B}_{\mathrm{y},}$ = Quantity of woody biomass saved (substitute or displayed)in tone

$\mathrm{f}_{\mathrm{NRB,y}}$ = Fraction of woody biomass saved by the project activity in year y that can be established as non-renewable biomass

$\mathrm{NCV}_{\mathrm{Biomass}}$ =Net calorific value of the non-renewable woody biomass that is Substituted (IPCC Change default for wood fuel, 0.015 TJ/ton) and charcoal 0.029TJ/ton

$\mathrm{EF}_{\text{project fosilfuel}}$ =Emission factor for the substitution of non-renewable woody biomass by similar consumers. Use a value of 81.6 tCO_2/TJ fuel wood and13.6 tCO/TJ Charcoal

η_{old} =10% [The default value of 10% was applied as the systems to be replaced are three Stone fires

$$\mathrm{B}_{\mathrm{y}} = \mathrm{B}_{\text{old, cooking stove}} \times \left(1 - \frac{\eta_{\mathrm{old}}}{\eta_{\text{new ICS}}}\right) --7$$

Where

$\eta_{\text{new ICS}}$ = the efficisncy of improved cooking stove in the study

$B_{\text{old ,cooking stove}} = B_{\text{y,deivce}} \times L_y$---8

Where

$B_{\text{y,deivce}}$ =Average annual consumption of woody biomass per appliance in tones per year

L_y =The default net to gross adjustment factor of 0.95 has been applied to account for leakages:

$B_{\text{y,device}} = B_{\text{old, caption}} \times N_{\text{resdent household}} \times FW_{\text{proportion}}$-------------------------------------9

Where

$B_{\text{old, caption}}$ =Average baseline fuel wood consumption in tones per capita per year

$FW_{\text{proportion}}$ = Proportion of household fuel wood consumed by cooking stove .Use 41.50% for cooking application

$B_{\text{old,capion}} = \frac{HC_{\text{fuel wood,usage,y}}}{HC_{\text{population ,y}}}$---10

$B_{\text{old,capion}} = 0.689\text{t/year for fuel wood and charcoal o. }115\text{t/year}$

$HC_{\text{fuel wood,usage,y}} = 58{,}134{,}125\text{t/year}$

$HC_{\text{population ,y}} = 84{,}320{,}987$(Ethiopia, C. S. A. (2012)

$HC_{\text{fuel wood,usage,y}}$ = fuel wood consumtion incubic meter × wood density----------------11

- fuel wood consumtion incubic meter = 80,185,000m^3 (UN, UNSD, 2013)

- wood density = $\frac{0.727\text{t}}{m^3}$ (FAO, 2004)

4. RESULTS AND DISCUSSION

4.1. Results

Five different stoves were tested in the laboratory and the results were tabulated. Fuel used to test the stoves was wood and charcoal. Efficiency of these five stoves was measured by using the WBT protocol. The average values of efficiency, specific fuel consumption time to boil produced for the cold start; hot start and simmering are presented. During each phases of WBT, the amount of water and evaporated water was measured. Fuel and remaining charcoal were weighed by separating the fuel at the end of the test. The temperatures and elapsed time were also recorded continuously. These measurements were used to evaluate the stove performance at low or high power phases (GACC, 2014)

4.1.1. Thermal efficiency

The efficiency of all five cooking stoves during cold start, hot start and simmering phases are measured in % and all the experiment replicated three times and the average value were taken. Test result of thermal efficiency with wood and charcoal in water boiling test is given in Fig 4.1 and (Table 2) . The thermal efficiency for cold start of three stone cook stove were 13 % and improved cooking stove were in the range of 25-32 % of solid fuels in the study. However, the thermal efficiency of wood stoves was in the range of 25-27 % with and charcoal stoves were in the range of 26-32 % . In general, the thermal efficiency of cooking stoves used in the study are listed in their order from high efficiency to low efficiency; charcoal stove (Lakech, Flexy, Mirchaye) and wood stove (Flexy, Tikikil, three stone stove) which is shown in the tables mentioned below. The thermal efficiency of the charcoal stoves of Lakech stove showed a higher efficiency than the two stove and from the wood stoves Flexy stove was better than the two stoves .

Table: 2 .The Efficiency of Biomass Cook Stove in Cold Start

Type of fuel	Type of stove	Unit	Three trials test			Average
			Test- 1	Test- 2	Test -3	
Charcoal	Lakech	%	32	32	32	32
	Flexy	%	30	28	31	30
	Mirchaye	%	26	26	27	26
Wood	Flexy	%	27	27	26	27
	Tikikil	%	25	26	25	25
	Three stone	%	14	13	13	13

Source:own experimental value ,2019

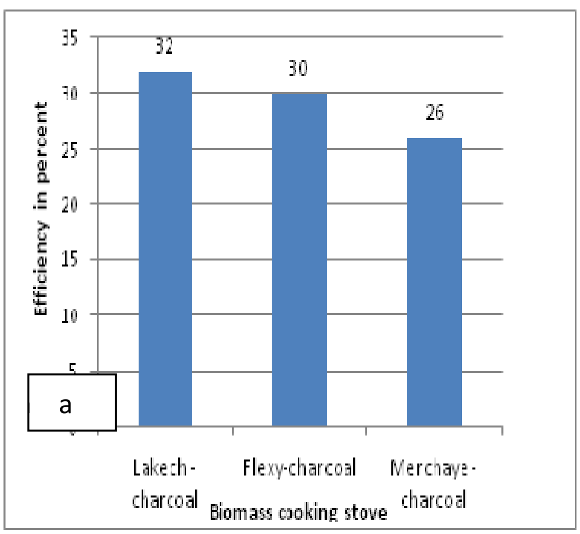

Fig: 4.1.Thermal efficieny of charcoal stove (a) and wood stove(b)

4.1.2. Variation of specific fuel consumption

The specific fuel consumption of all five cooking stoves during cold start, hot start and simmering phases are measured in g/liter and all the experiment replicated three times and the average value were taken . The consumption for biomass cooking stove was shown in Fig 4.2 and (Table 3) . From all charcoal cook stoves: Flexy, Lakech and irchaye from this, Lakech cooking stove consume low fuel. On the other hand, the specific fuel consumption of wood cooking stove , Flexy cooking stove consumes lower fuel than the other two wood stoves .

Table: 3. Specific fuel consumption at cold start

Type of fuel	Type of stove	unit	Three trials test			average
			Test- 1	Test- 2	Test -3	
charcoal	Mirchaye	g/liter	59	58	60	59.2
	Flexy	g/liter	53	54	52	52.8
	Lakech	g/liter	45	51	48	48.2
Wood	Three stone	g/liter	121	141	135	251.7
	Tikikil	g/liter	140	142	143	141.9
	Flexy	g/liter	243	261	251	132.3

Source:Own experimental value ,2019

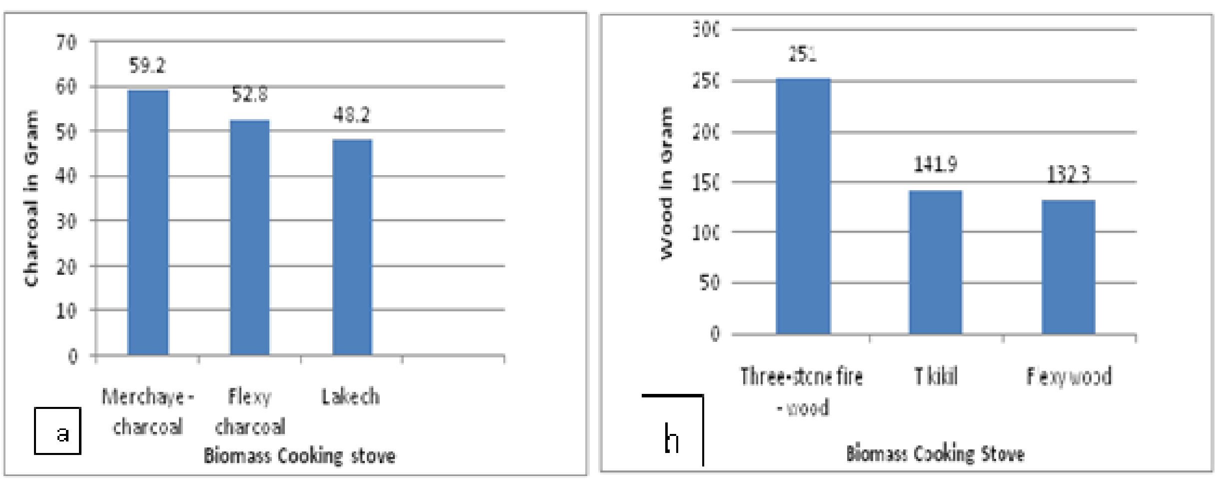

Fig:4.2. specific fuel consumption of charcoal stove (a) and wood stove (b)

4.1.3. Time to boil

The time-to-boil is the amount of time it takes 2.5 L of water to reach the local boiling point which is 92℃. The Time-to-boil in this WBT was recorded from when the charcoal or wood was considered lit until the water started boiling. The charcoal or wood was qualitatively determined to be lit when enough charcoal or wood was burning such that the fire would not die out with the addition of a pot being set on it to heat . In Fig 4.3 and (Table 4) was showed Flexy, Lakech and Mirchaye charcoal cook stove and Flexy, Tikikil and three stone fires wood cooking stove . charcoal cook stove Flexy was boiled by shorter time than the two stoves. Wood cook stove Three-stone fire was boiled by shorter time than the two cook stove.

Table 4 .Time to boil at cold start charcoal stove

Type of fuel	Type of stove	unit	Three trials test			Average
			Test- 1	Test- 2	Test -3	
charcoal	Mirchaye	min	22	23	23	23.0
	Lakech	min	20	24	20	21.7
	Flexy	min	21	20	19	20.4
wood	Three stone	min	17	19	18	17.8
	Flexy	min	19	17	18	18.1
	Tikikil	min	20	21	21	21.1

Source: own experimental value ,2019

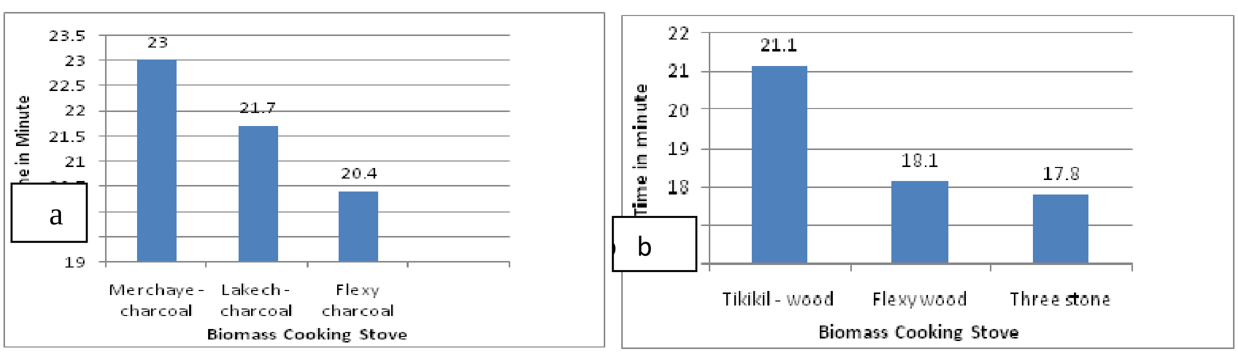

Fig: 4.3. Duration of timeto boil charcoal stove (a) and wood stove (b)

4.1.4. Emission performance

CO concentrations during the test for each stove for the charcoal Lakech, flexy, Mirchaye and for the wood Tikikil, flexy, three stone stove were measured separately. It can be seen that the CO emission from the three-stone stove was higher than that of the ICS. The average amount of CO emission from the wood cook stove ;three-stone stove, Flexy and Tikikiwas ,also charcoal improved cooking stove; Flexy, Lakech and Mirchaye, were shown in Fig. 4.4 and (Table .5). From wood stove the three-stone stove was the main contributor for higher CO emission because of Uncontrolled situations in (Gonçalves et al., 2010). Tryner,(2014) also observed that adding solid fuel during the stove operation makes a sharp increase in CO emission. From charcoal stove Flexy was emitte high emission of CO than the two cook stove. The results showed that even though each stove has its exclusive behavior, fuel feeding has two direct effects in both the stoves; decreasing the flame temperature, and at the same time, increasing CO.

Table :5.The emission of carbon monoxide

Type of fuel	Type of stoves	CO										Average
Wood stove	Flexy	520	695	758	581	473	425	233	143	55	24	391
	Tikikil	175	453	579	681	479	418	294	207	140	95	353
	Three stone	1185	1877	1835	1621	1460	1348	1292	205	168	140	1113
Char Coal	Flexy	47	91	117	145	164	147	117	96	59	42	103
	Lakech	30	38	51	60	65	62	59	55	51	35	51
	Mirch aye	5	48	69	94	100	79	61	34	19	15	52.4

Source: own experimental result ,2019

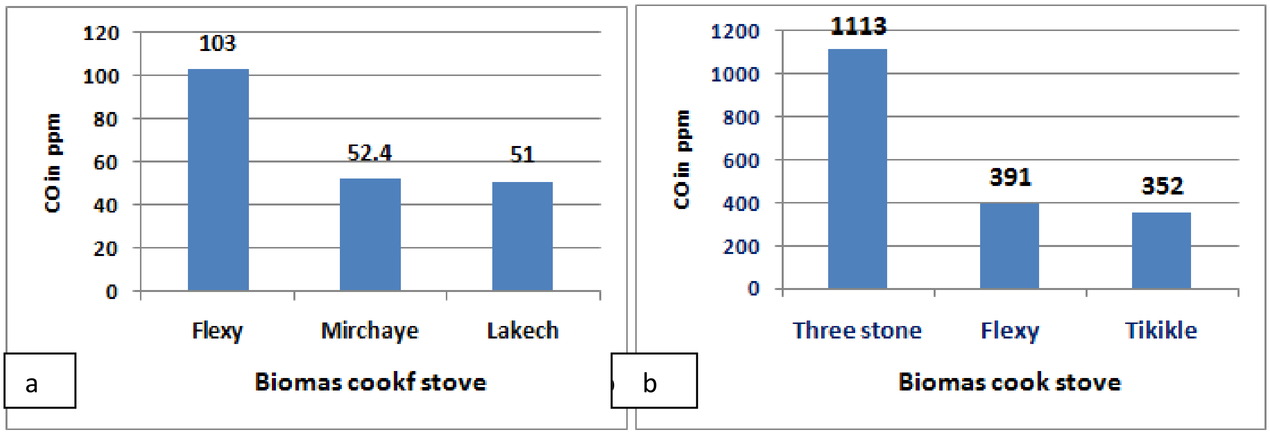

Fig: 4.4. Amount pf CO in ppm charcoal stove (a) and wood stove (b)

4.1.5. Particulate Matter from cooking stove

PM 2.5emissions from wood cook stove Flexy , Tikikil and three stone stove from char coal stove; Flexy, Lakech and Mirchaye were shown in Fig. 4.5 and Table 6 . The PM 2.5 of the cooking stove was taken the average emitted in one hour by the interval of 5min.Wood stove, Three stone stove releases high amount of pm 2.5 and Charcoal cooking stoves, Mirchaye stoves released high amount of pm 2.5.

Table: 6.The amount of particulate matter

Type of fuel	Type of stoves	PM												Avarge
Wood	Flexy	12	271	541	999	765	643	327	212	109	67	25	11	332
	Tikikil	7	116	999	763	665	606	456	314	116	42	25	11	342
	Three stone	14	999	999	999	999	999	972	586	492	204	82	14	613
Charcoal	Flexy	11	22	32	34	54	85	103	70	65	45	25	19	47
	Lakech	8	18	40	118	141	117	73	71	44	34	26	12	59
	Mirchaye	9	270	331	718	664	587	246	194	149	95	43	13	277

Source: own Experimental result,2019

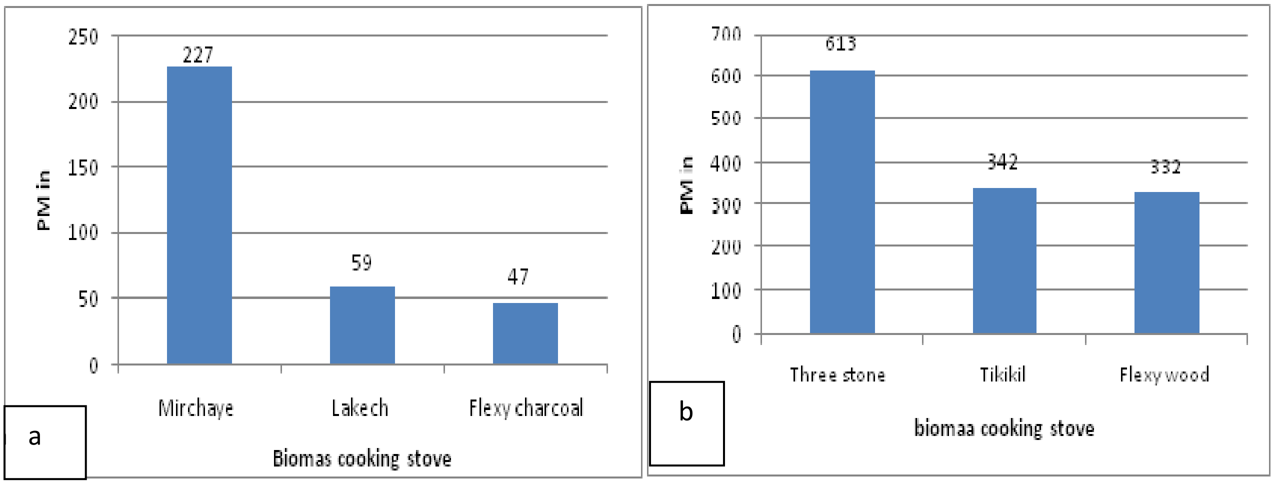

Fig: 4.5 Particulate matter of charcoal stoves (a) and (b) wood stoves

4.1.6. Carbondioxide

The emission of Carbon Dioxide for wood cook stove; Flexy, Three stone stove and Tikikil and charcoal cook stove ;Flexy, Lakech and Mirchaye were measured . The result shows in tabe 7. Depending of the average result Three stone fire from wood stove emits more CO_2 than the rest of two and charcoal improved cook stove measure neglegeble emission of CO_2.

Table: 7. The emission of carbondioxide

Type of fuel	Type of stove	Emission of CO_2									average
Wood	Flexy	0	1.38	1.36	1.7	1.99	1.9	0	0	0	0.93
	Tikikil	0.032	0.029	0.035	0.046	0.045	0.042	0.038	0.034	0.029	0.033
	Three stone	1.04	1.42	1.64	1.75	1.74	1.91	1.76	1.70	1.59	1.62
Charcoal	Flexy	0	0	0	0	0	0	0	0	0	0
	Lakech	0	0	0	0	0	0	0	0	0	0
	Mirchaye	0	0	0	0	0	0	0	0	0	0

Source: Own Experimental result,2019

4.1.7. Nitrogen dioxide

The emission of Nitrogen dioxide for wood cook stove; Flexy, Three stone stove and Tikikil and charcoal cook stove ;Flexy, Lakech and Mirchaye were measured . The result shows in tabe 8. Depending on the average of result Three stone fire from wood stove emits more Nitrogen dioxide than the rest of two and charcoal improved cook stove Flexy emits more Nitrou oxide than the two cook stove .

Table 8: The Emmision of Nitrogen dioxide

Type of fuel	Type of stove	Emission of Nitrogen dioxide ppm										average
Wood	Flexy	0	1	4	6	8	7	6	4	3	1	4
	Tikikil	1	3	2	3	5	4	2	0	0	0	2
	Three stone	2	6	9	12	9	8	5	3	4	0	5.8
Charcoal	Flexy	0	0	0	1	1	1	1	1	1	0	0.6
	Lakech	0	0	0	0	0	0	0	0	0	0	0
	Mirchaye	0	0	0	0	0	0	0	0	0	0	0

Source: Own Experimental result,2019

4.1.8. Reduction potential Green House Gas from cooking stoves

GHG reduction potential from the wood stove ;Flexy and Tikikil and charcoal stove Flexy , Lakech and Mirchaye cooking stoves were shown in table 9. GHG reduction potential of the cooking stove was taken from estimate of the carbon dioxide (CO_2) reduction calculated using the AMS-II G methodology (UNFCC, 2012). The emission reduction potential of each improved cooking stoves, in terms of carbon credit saving, was calculated For wood stoves: Flexy and Tikikil has shown emission reduction potential of 1.11 t CO_2/device/year and 1.05 t CO_2/device/year respectively. Charcoal cooking stoves: Lakech, Flexy, and Mirchaye Stoves have shown emission reduction potential of 0.067 t CO_2/device/year,0.065 t CO_2/device/year and 0.058 t CO_2/device /year respectively (Table 9).

Table 9:Emission reduction potential

Type of fuel	Types of stove	Emission reduction potential in t CO/device/year
wood	Flexy	1.11
	Tikikil	1.05
charcoal	Lakech	0.067
	Flexy	0.065
	Mirchaye	0.058

Table: 10.Summary of The Result

No	Criteria	Best stove		Reference
		Wood stove	Charcoal stove	
1	Thermal efficies	Flexy	Lakech	Fig.4.1 and Table .2 Page 30
2	Fuel consumption	Flexy	Lakech	Fig.4.2 and Table .3 Page 31
3	Time –to-boil	Three stone	Flexy	Fig.4.3 and Table .4 Page 32
4	CO emmision	Tikikil	Lakech	Fig.4.4 ,page 34 and Table .5, Page 33
5	Pm 2.5	Flexy	Flexy	Fig.4.5, page35 and Table .6, Page 34
6	CO_2 emmision	Tikikil	Lakech,Flexy,Mirchaye	Table .7,page -35
7	N O_2 emission	Tikikil	Lakech and mirchaye	Table .8, page -36
8	Emmisireduction potential	Flexy	Lakech	Table .9,page -37

4.2. Discussion

This study has only the objective of evaluating the performance of five cooking stoves in Addis Ababa Ethiopia. Studies so far have been conducted on the evaluating the performance of these cooking stoves. However, study on comparison of cooking stoves including Flexy Cooking Stoves has not been conducted in detail because Flexy is a new entrant to the market. As result, this study tries to evaluate the performance of these cooking stoves and present the result in the above section. This part of the study assesses the implication of the results found in the laboratory.

4.2.1. Performances of thermal efficiency

The thermal efficiency of wood stove ; Tikikil and Three stone Stove charcoal stove Mirchaye, Lakech and had been measured by different institutions and studies. The results of these studies were presented in the following Table 10.

Table 11 : Thermal efficiency of Alternative energy technology development Laboratory and GTZ

Type of fuel	Stoves	Test methodology	Thermal efficiency (%)	Source
Char coal	Lakech	WBT	32	GTZSUN: Energy,2007
	Mirchaye	WBT	24	AETDPL, 2003
Wood	Three stones stove	WBT	12	GTZ SUN: energy, 2009
	Tikikil	WBT	26	

Although the thermal efficiency of research results from previous studies reflect the same , three stone stove were in cold start studied by Suresh *et a*l., (2016) ,Nandi *et al*., (2015),Wang *et a*l.,(2015), Rasoulkhani *et al*.,(2018),Raman *et a*l.,(2014) and found efficiency of

14%,9.8%,16.4%,12.6% ,16.9% respectively. They also observed that the thermal efficiency of improved biomass cooking stove studied by different researcher, In Iran, Rasoulkhani *et al*., (2018) the η of the ICS in the cold start phase was approximately 35% ,In India, Raman *et al* ., (2014) the η of the of the forced draft improved cooking stove in the cold start phase was 47%, Also in India ,Suresh et al.(2016) the thermal efficiency of fuel wood improved cooking stoves was in the range of 30-37% with different types of solid fuels used. In Kenya, Lefebvre,(2016) the improved charcoal cooking stove is called Kenya Ceramic Jiko the thermal efficiency was 24.3%.(Workeneh Gashie, 2005) studied Lakech without Pan Seat whose value was about 30%.

Efficiency of stove depends on many factors either they will increases or decreases the efficiency. The stoves also differed in the following characteristics: air flow features (e.g., fan, chimney), fuel size, and type of fuel feeding system (Yip *et al*.,2017). Among these factors, fuel type and size play a key role on the performance of a stove (Raman *et a*l., 2013).

This study has measured the thermal efficiency in different scenario; namely using wood and charcoal.

When it is seen from the efficiency side, with cold start experiment using charcoal, Lakech Cooking Stove performs better than Flexy. On the other hand, while using wood as a fuel with same cold start, Flexy takes the first rank and Tikikil the second in terms of thermal efficiency. This data implies that Flexy is the better cooking stove for using wood as fuel and on the other side, Lakech is better for using charcoal as fuel. According to the results, communities who have better access for wood need to prefer Flexy and those who have good opportunity and for charcoal prefer to use Lakech.

4.2.2. Variation of specific fuel consumption

The fuel consumption aspect of using cooking stove is very critical for environment and health. (MacCarty *et al*., 2008) state that the amount of fuel burned is directly related to the amount of climate- and health-harming emissions produced. While using charcoal as fuel, Lakech consume less charcoal than the other two cooking stoves and followed by Flexy. When using wood is as fuel, Three-stone stove consumes more wood than Tikikil. Based on these findings, Lakech was better fitting cooking stove for people who have a better access for charcoal. Three stone stove consumes more wood than the other stoves. According to Lask *et a*l., (2015) Improved cooking stoves saved fuel compared to the traditional cooking stove .This implies that using three stone stove may have a negative impact on vegetative cover of the environment. Communities who use three stone stove may have a great impact on environment degradation.

4.2.3. Time to boil

The time to boil for these five different cooking stoves is measured using 2.5 L of water to reach the local boiling point. According to the data recorded, using charcoal, Flexy boils the water in shorter time than the other two cooking stoves. It boils the water with 20 minutes and followed by Lakech which boils within 22 minutes. The three stone stove boils the water in shorter time than Tikikil and Flexy while using wood. It boils within about 17 minutes. This result was showed that when used three stone stove , the wind flow in the stove bottom is increased the heat generation and accelerate the cooking process to reduce the time to boil compared to that of the improved cooking stove.

Different studies were showed similar results .For example *Lask et al*.(2015) in the University of California Berkeley, Berkeley, USA traditional stove brought water to boil at least 15 minutes faster than any of the other stoves on average, while the improved cook stoves performed fairly similarly to one another,this means the time of cooking for the same cooking task is dependent on the amount of heat generation and utilization of heat by the specific type of stove (Suresh et al., 2016). Although (MacCarty *et al*., 2008) it was shown that 2.5L of water boil by three stone stove in 22min and charcoal jiko (improved cooking stove) 27min..

4.2.4. Emission performance

This study also measures the emission of three green house gases namely Carbon Monoxide (CO), Carbon Dioxide and Nitrogen dioxide using both charcoal and wood. Wood-burning produced extremely higher emissions of carbon monoxide. The release of Carbon mono oxide for wood stove Flexy, Three stone stove and Tikikil and charcoal Flexy, Lakech, Mirchaye were average units are presented. According to the result,. The three stone stove was emited high emission of CO than Tikikil and Flexy. This implies that using wood, the Tikikil cooking stove is preferred to reduce the emission of CO. While using charcoal, Lakech was less emission of CO. (Fikadu Mamuye *et al*., 2018) reported that Mirchaye and Lakech improved charcoal stove emit less amount Carbon Monoxide.

The emission of PM for five cooking stoves namely; Flexy, Tikikil, three stone stove, Lakech and Mirchaye were measured in the laboratory. According to the result found, looking at the average emission of PM, Flexy Cooking Stove (Charcoal as fuel) release less PM and followed by Lakech Cooking Stove. The three stone Stove emits more PM than any other cooking stoves.(Fikadu Mamuye et al., 2018) also found that Mirchaye and Lakech emit less PM as compared to Traditional Metal stove. This data is near to the result found in the study for the emission for Flexy wood cooking stove .

These results show that the three stone stove has a potential to pollute the environment more seriously than the other cooking stoves with the emission of great amount PM. On the other hand, Flexy has a less impact on surrounding in terms of emitting PM using charcoal as fuel and Mirchaye takes the second position in this aspect. Using wood as fuel, Flexy and Tikikil release almost equal amount of PM and their impact on the environment is nearly the same. It is advisable and recommended to use Flexy and Lakech from char coal stove and from wood stove Tikikil and flexy for the community to have clean environment in terms of particulate matter. It is also advisable to avoid using three stone stove to keep the surrounding environment clean from particulate matter.

The emission of Carbon Dioxide for Flexy, Traditional and Tikikil was also measured using wood. The result shows that still three stone stove emits more CO_2 than the rest of two. Like the case of CO, Tikikil Stove emits less carbondioxide using wood as fuel. The implication here also that Traditional Cooking Stove release high carbondioxide emission in air. In terms of carbon emission using wood as fuel, the Tikikil Stove is preferable for the community to reduce pollution of the air and damaging the environment.char coal cooking stove Lakech Flexy and Mirchaye reales negligible aount of carbondioxide .

One of the gases released during combustion was Nitrogen dioxide and the extent of emitting this gas was measured. From wood stove three stone stove was emited high amount of Nitrogen dioxide than the other cook stove. From charcoal stove flexy was emited high amount of nitrous oxide than the othe two stove .

4.2.5. The emission reduction potential of GHG from cooking stove

According to the result the emission reduction potential of the improved cooking stove, in terms of carbon credit saving, was calculated as 1.11 t CO_2 /device /year for Flexy wood stove and 1.05 t CO_2 / device / year for Tikikil biomass cooking stove. With these result ,Flexy wood stove is better than Tikikil biomass cooking stove .According to world vision Ethiopia (2013),improved cooking stoves emit 1.14 t CO_2 / device / year .This data is near to the result found in the study for the emission reduction potential of GHG in t CO_2 / device / year for Flexy wood cooking stove .For charcoal cooking stoves ,Lakech biomass cooking stove which was calculated as 0.067 t CO_2 / device / year is better than Mirchaye and Flexy biomass cooking stoves which was calculated as 0.065 t CO_2 / device / year and 0.058 t CO_2 / device / year respectively . The following table shows result of t CO_2 / device / year for each ICS.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusion

The study was aimed to evaluate biomass improved cooking stove and compare them with three stone stove. In this study experimental method in the laboratory was applied. The primary data was presented and analyzed to reach at results.

According to the findings, in terms thermal efficiency, with cold start experiment using charcoal, Lakech cooking stove performed better and followed by Flexy. On the other hand while using wood as a fuel with same cold start, Flexy ranked first rank in thermal efficiency and Tikikil took the second position. In terms of fuel consumption, while using charcoal as fuel, Lakech consumed less charcoal and followed by Flexy. The time to boil for these five different cooking stoves is measured. As per the results of the study, using charcoal, Flexy boils the water in shorter time than the other two cooking stoves.

From wood stove ; three stone stove was emitted higher CO than Tikikil and Flexy. Looking at the average emission of PM from charcoal stove, Mirchaye was realed higher amount than Flexy and Lakech . In the case of emission of CO_2 and NO_2 three stone stove emited higher amount than Tikikil and Flexy wood stove. In charcoal stove Flexy emited some amount of NO_2 . In terms of emmision reduction potential Flexy wood stove more prefrable than the other stoves in terms of reduction potential ..

According to the results, the study results showed that in terms of thermal efficiency, specific fuel consumption, gas emission, and particulate matter of the ICS were better than the three stone stove. The improved cooking stoves; namely Lakech and Flexy, were better for the community.

5.2. Recommendation

The findings of the research show that cooking stoves are made at different level of efficiency and qualities.

The following recommdations are forwarded based on this study

- Further study shoud be conducted using controlled cooking stove test (CCT) and Kietchen Performance Test (KPT),
- The quality of the hood system used for this study should be improved with better accuracy instruments so that the result are reliable,
- Industrial manufacturing of improved cook stoves will generate a uniform size improved cook stoves so that the variability of their performance could be reduced

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APPENDIX.1

Appendix 1: Water Boiling Test of Flexy Cooking Stove by Charcoal

1. HIGH POWER TEST (COLD START)	units	Test 1	Test 2	Test 3	Average	St De
Time to boil Pot # 1	min	21	20	19	20.4	1.0
Temp-corrected time to boil Pot # 1	min	21	20	19	20.2	0.8
Burning rate	g/min	6	6	6	6.1	0.3
Thermal efficiency	%	30%	28%	31%	30%	1%
Specific fuel consumption	g/liter	53	54	52	52.8	0.9
Temp-corrected specific consumption	g/liter	52	53	52	52.4	0.8
Firepower	watts	2,718	2,937	2,943	2866	128.1

2. HIGH POWER TEST (HOT START)	units	Test 1	Test 2	Test 3	Average	St Dev
Time to boil Pot # 1	min	17	16	17	16.5	1.0
Temp-corrected time to boil Pot # 1	min	17	15	17	16.4	1.0
Burning rate	g/min	6	7	7	6.6	0.5
Thermal efficiency	%	32%	31%	32%	32%	1%
Specific fuel consumption	g/liter	45	46	50	46.7	2.5
Temp-corrected specific consumption	g/liter	45	45	50	46.5	2.6
Firepower	watts	2,881	3,299	3,160	3114	213.1

3. LOW POWER (SIMMER)	units	Test 1	Test 2	Test 3	Average	St Dev
Burning rate	g/min	2	2	1	1.5	0.7
Thermal efficiency	%	36%	37%	35%	36%	1%
Specific fuel consumption	g/liter	42	42	35	39.3	4.0
Firepower	watts	903	903	311	706	341.7
Turn down ratio	--	3.01	3.25	9.45	5.24	3.7

Appendix 2: Water Boiling Test of Flexy Cooking Stove by Wood

1. HIGH POWER TEST (COLD START)	units	Test 1	Test 2	Test 3	Average	St Dev
Time to boil Pot # 1	min	19	17	18	18.1	1.5
Temp-corrected time to boil Pot # 1	min	20	17	19	18.7	1.6
Burning rate	g/min	14	18	16	16.0	2.2
Thermal efficiency	%	27%	27%	26%	27%	1%
Specific fuel consumption	g/liter	121	141	135	132.3	10.1
Temp-corrected specific consumption	g/liter	125	144	139	136.0	9.8
Firepower	watts	4,330	5,709	5,024	5021	689.8
2. HIGH POWER TEST (HOT START)	**units**	**Test 1**	**Test 2**	**Test 3**	**Average**	**St Dev**
Time to boil Pot # 1	min	17	14	17	15.6	1.7
Temp-corrected time to boil Pot # 1	min	17	14	17	16.0	1.8
Burning rate	g/min	10	14	15	13.1	2.7
Thermal efficiency	%	29%	32%	29%	30%	2%
Specific fuel consumption	g/liter	69	85	111	88.3	21.4
Temp-corrected specific consumption	g/liter	71	87	114	90.9	21.7
Firepower	watts	3,157	4,497	4,698	4117	837.9

3. LOW POWER (SIMMER)	units	Test 1	Test 2	Test 3	Average	St Dev
Burning rate	g/min	6	8	5	6.4	1.6
Thermal efficiency	%	34%	43%	58%	45%	12%
Specific fuel consumption	g/liter	155	355	194	234.4	105.9
Firepower	watts	1,869	2,593	1,609	2024	510.0
Turn down ratio	--	2.32	2.20	3.12	2.55	0.5

Appendix 3: Water Boiling Test of Lakech Cooking Stove by Charcoal

1. HIGH POWER TEST (COLD START)	**Units**	**Test 1**	**Test 2**	**Test 3**	**Average**	**St Dev**
Time to boil Pot # 1	Min	20	24	20	21.7	2.2
Temp-corrected time to boil Pot # 1	Min	22	26	21	23.1	2.7
Burning rate	g/min	5	5	5	5.2	0.3
Thermal efficiency	%	32%	32%	32%	32%	0%
Specific fuel consumption	g/liter	45	51	48	48.2	3.1
Temp-corrected specific consumption	g/liter	48	55	50	51.3	3.7
Firepower	Watts	2,425	2,280	2,581	2428	150.4
2. HIGH POWER TEST (HOT START)	**Units**	**Test 1**	**Test 2**	**Test 3**	**Average**	**St Dev**
Time to boil Pot # 1	Min	19	17	18	18.1	1.5
Temp-corrected time to boil Pot # 1	Min	21	18	19	19.3	1.4
Burning rate	g/min	5	6	5	5.4	0.5
Thermal efficiency	%	34%	33%	34%	34%	1%
Specific fuel consumption	g/liter	41	41	40	40.9	0.7
Temp-corrected specific consumption	g/liter	44	45	42	43.6	1.3
Firepower	Watts	2,336	2,803	2,434	2524	246.3

3. LOW POWER (SIMMER)	**Units**	**Test 1**	**Test 2**	**Test 3**	**Average**	**St Dev**
Burning rate	g/min	2	2	2	1.6	0.1
Thermal efficiency	%	49%	45%	41%	45%	4%
Specific fuel consumption	g/liter	39	36	33	36.2	3.1
Firepower	Watts	820	768	737	775	42.0
Turn down ratio	--	2.96	2.97	3.50	3.14	0.3

Appendix 4: water boiling test of Mirchaye cooking stove by charcoal

1. HIGH POWER TEST (COLD START)	units	Test 1	Test 2	Test 3	Average	St Dev
Time to boil Pot # 1	min	22	23	23	23.0	0.6
Temp-corrected time to boil Pot # 1	min	24	25	24	24.5	0.6
Burning rate	g/min	6	6	6	6.0	0.2
Thermal efficiency	%	26%	26%	27%	26%	1%
Specific fuel consumption	g/liter	59	58	60	59.2	1.3
Temp-corrected specific consumption	g/liter	63	62	63	63.1	0.6
Firepower	watts	2,905	2,725	2,823	2818	89.8
2. HIGH POWER TEST (HOT START)	**units**	**Test 1**	**Test 2**	**Test 3**	**Average**	**St Dev**
Time to boil Pot # 1	min	18	18	18	18.1	0.6
Temp-corrected time to boil Pot # 1	min	20	19	19	19.4	0.5
Burning rate	g/min	6	6	6	6.0	0.2
Thermal efficiency	%	28%	29%	30%	29%	1%
Specific fuel consumption	g/liter	46	46	45	45.8	0.6
Temp-corrected specific consumption	g/liter	49	50	47	48.9	1.3
Firepower	watts	2,803	2,959	2,754	2839	107.0

3. LOW POWER (SIMMER)	units	Test 1	Test 2	Test 3	Average	St Dev
Burning rate	g/min	2	2	2	1.7	0.1
Thermal efficiency	%	45%	42%	47%	44%	2%
Specific fuel consumption	g/liter	38	36	35	36.2	1.3
Firepower	watts	810	779	758	782	26.1
Turn down ratio	--	3.59	3.50	3.72	3.60	0.1

Appendix 5: Water Boiling Test of Tikikil Cooking Stove by Wood

1. HIGH POWER TEST (COLD START)	Units	Test 1	Test 2	Test 3	Average	St Dev
Time to boil Pot # 1	Min	20	21	21	21.1	0.6
Temp-corrected time to boil Pot # 1	Min	21	22	22	21.9	0.5
Burning rate	g/min	15	14	15	14.7	0.4
Thermal efficiency	%	25%	26%	25%	25%	1%
Specific fuel consumption	g/liter	140	142	143	141.9	1.5
Temp-corrected specific consumption	g/liter	147	146	150	147.5	2.0
Firepower	Watts	4,741	4,497	4,594	4611	123.1
2. HIGH POWER TEST (HOT START)	**Units**	**Test 1**	**Test 2**	**Test 3**	**Average**	**St Dev**
Time to boil Pot # 1	Min	17	17	18	17.5	1.0
Temp-corrected time to boil Pot # 1	Min	17	18	19	18.2	1.0
Burning rate	g/min	15	15	14	14.6	0.3
Thermal efficiency	%	30%	29%	27%	29%	2%
Specific fuel consumption	g/liter	109	118	118	114.9	5.2
Temp-corrected specific consumption	g/liter	114	121	124	119.7	5.1
Firepower	Watts	4,594	4,647	4,488	4576	80.9

3. LOW POWER (SIMMER)	Units	Test 1	Test 2	Test 3	Average	St Dev
Burning rate	g/min	8	6	7	6.7	0.8
Thermal efficiency	%	31%	39%	35%	35%	4%
Specific fuel consumption	g/liter	244	191	211	215.3	27.0
Firepower	Watts	2,382	1,856	2,077	2105	264.2
Turn down ratio	--	1.99	2.42	2.21	2.21	0.2

Appendix 6: Water Boiling Test of Traditional Cooking Stove By Wood

1. HIGH POWER TEST (COLD START)	units	Test 1	Test 2	Test 3	Average	St Dev
Time to boil Pot # 1	min	17	19	18	17.8	1.5
Temp-corrected time to boil Pot # 1	min	17	20	18	18.4	1.4
Burning rate	g/min	33	30	32	31.3	1.6
Thermal efficiency	%	14%	13%	13%	13%	0%
Specific fuel consumption	g/liter	243	261	251	251.7	9.0
Temp-corrected specific consumption	g/liter	253	269	259	260.4	7.8
Firepower	watts	10,218	9,284	10,015	9839	490.9

2. HIGH POWER TEST (HOT START)	units	Test 1	Test 2	Test 3	Average	St Dev
Time to boil Pot # 1	min	14	15	17	14.9	1.5
Temp-corrected time to boil Pot # 1	min	14	15	17	15.4	1.5
Burning rate	g/min	32	26	25	27.8	3.8
Thermal efficiency	%	17%	19%	17%	18%	1%
Specific fuel consumption	g/liter	197	172	187	185.2	12.3
Temp-corrected specific consumption	g/liter	205	178	193	191.9	13.8
Firepower	watts	10,097	8,223	7,871	8730	1,196.2

3. LOW POWER (SIMMER)	units	Test 1	Test 2	Test 3	Average	St Dev
Burning rate	g/min	7	7	7	7.1	0.3
Thermal efficiency	%	33%	31%	35%	33%	2%
Specific fuel consumption	g/liter	224	233	221	226.0	6.6
Firepower	watts	2,202	2,311	2,153	2222	81.1
Turn down ratio	--	4.64	4.02	4.65	4.44	0.4

Appendix 7: Data Entry Sheets of Flexy Wood Cooking Stove

SHELL FOUNDATION HEH PROJECT WATER BOILING TEST
DATA AND CALCULATION FORM (the form can be used with stoves that cook between one and four pots)*
Shaded cells require user input; unshaded cells automatically display outputs
Qualitative data

Name(s) of Tester(s)	Senait and Negussei
Test Number	1
Date	14/06/2011
Stove type/model	Flexy
Location	energy lab
Type of fuel	50 Eucalyptus Globulus (Southern Blue Gum, Fever Tree)
Wind conditions	No wind

*Note, if you are testing a multi-pot stove, the data entry places in the simmering test for pots other than the primary pot are left blank intentionally because the simmering test cannot account for pots other than the primary pot.

If possible, enter a locally derived calorific val… Enter the value in cell E19 if the calorific value i… dry fuel (0% MC). Use cell E22 if it is for moist f… a local calorific value can not be obtained, cho… the closest fuel from this menu.

Initial Test Conditions

Data	value	units	label	Data	value	units	label
Air temp	22.4	ºC		Dry weight of Pot # 1 (grams)	190	g	P1
Average dimensions of fuel (if solid)		cm x cm x cm		Dry weight of Pot # 2 (grams)		g	P2
Gross calorific value (dry fuel)	20,160	kJ/kg	HHV	Dry weight of Pot # 3 (grams)		g	P3
Net calorific value (dry fuel)	18,840	kJ/kg	LHV	Dry weight of Pot # 4 (grams)		g	P4
Wood moisture content (% - wet basis)	8%	%	m	Weight of container for char (grams)	207	g	k
Effective calorific value (accounting for fuel moisture)	17,129	kJ/kg	C_{eff}	Local boiling point	92.0	ºC	T_b

Appendix 8: Data Entry Sheets of Mirchaye

SHELL FOUNDATION HEH PROJECT WATER BOILING TEST
DATA AND CALCULATION FORM (the form can be used with stoves that cook between one and four pots)*
Shaded cells require user input; unshaded cells automatically display outputs

Qualitative data

Name(s) of Tester(s)	Senait and Negussei
Test Number	1
Date	13/6/2011
Stove type/model	Merchaye
Location	energy lab
Type of fuel	4 Charcoal
Wind conditions	2 No wind

*Note, if you are testing a multi-pot stove, the data entry places in the simmering test for pots other than the primary pot are left blank intentionally because the simmering test can not account for pots other than the primary pot.

If possible, enter a locally derived calorific value. Enter the value in cell E19 if the calorific value is f dry fuel (0% MC). Use cell E22 if it is for moist fuel. ...al calorific value can not be obtained, choose the closest fuel from this menu.

Initial Test Conditions

Data	value	units	label	Data	value	units	label
Air temp	18.2	ºC		Dry weight of Pot # 1 (grams)	190	g	P1
Average dimensions of fuel (if solid)	6	cm x cm x cm		Dry weight of Pot # 2 (grams)		g	P2
Gross calorific value (dry fuel)	29,400	kJ/kg	HHV	Dry weight of Pot # 3 (grams)		g	P3
Net calorific value (dry fuel)	28,200	kJ/kg	LHV	Dry weight of Pot # 4 (grams)		g	P4
Wood moisture content (% - wet basis)	3%	%	m	Weight of container for char (grams)	207	g	k
Effective calorific value (accounting for fuel moisture)	27,277	kJ/kg	c_{eff}	Local boiling point	92.0	ºC	T_b

Appendix 9 : Different Activities of Laboratory